SPECTRORADIOMETRIC INVESTIGATION OF THE TRANSMISSION OF VARIOUS SUBSTANCES

By W. W. Coblentz, W. B. Emerson, and M. B. Long

CONTENTS

	Page
I. Introduction	653
II. Group 1.—Various substances	654
1. Purple fluorite	654
2. Gelatin light filters	655
3. Gold-plated glass	655
4. Molybdenite	656
5. Chromium sulphate	657
6. Chrome alum	657
7. Cobalt chloride	657
8. Solutions of nickel salts	658
III. Group 2.—Various glasses	658
1. Red glasses	659
2. Orange glasses	660
3. Yellow glasses	661
4. Green glasses	662
5. Blue-green glasses	663
6. Blue glasses	664
7. Purple glasses	666
8. Amethyst glasses	667
9. Black glasses	668
10. Crookes's glasses	668
11. Colorless glasses	670
12. Unclassified glasses	671
IV. Summary	673
Appendix.—Transmission data of various glasses	674

I. INTRODUCTION

During the past few years radiometric determinations were made of the spectral transmission of radiant energy through various substances. These data are published in the present paper.

A practical application of these data may be made in isolating narrow spectral bands of radiation without the use of a spectrometer. In this manner it may be possible to obtain the spectral-energy distribution of stars which are too weak in energy for measurement after dispersion by a prism. The data are useful in eliminating scattered light in spectrophotographic and spectroradiometric work. In this laboratory some of the substances

described have been employed as screens for transmitting bands of spectral radiations in an investigation of the photoelectric sensitivity of various substances.

When it is possible to sacrifice spectral purity in order to obtain high intensity, some of these substances, which have bands of transmission which are 70 to 80 per cent at the maximum, may be more efficient than a spectrometer in producing stimuli of spectral radiation of high intensity and covering a large area.

The apparatus used for determining the transmissions in the visible (yellow to red) and infra-red parts of the spectrum consisted of a mirror spectrometer, a fluorite prism, and a vacuum bismuth-silver thermopile, described in previous papers.

Some of the data in the violet part of the spectrum (indicated by dotted lines in the illustrations) were taken from papers published by Luckiesh [1] and by Gage.[2] The rest of the data in the blue and violet were obtained by means of a lens spectrometer, a glass or quartz prism, a potassium photo-electric cell (constructed by Dr. Kunz), and a high-resistance Thomson galvanometer.[3]

II. GROUP 1.—VARIOUS SUBSTANCES

1. PURPLE FLUORITE

In view of the increased scarcity of fluorite for use as prisms, lenses, thin plates, etc., it was of interest to examine the transmission of colored fluorites.[4] The samples used in the present examination were of the purple variety. They contained streaks of material which were of light amethyst color; but as will be noticed presently in glasses, the effect of this coloring matter does not extend very far into the infra-red.

The transmission curve of two superposed plates (thickness 2.32 and 2.63 mm, respectively) is given in Fig. 1. The curve, *A*, is broken at 2μ ($\mu = 0.001$ mm), owing to the fact that the plates were reset. The surfaces did not take a uniformly high polish (appeared etched in spots), which accounts for part of the low transmission, which at best could not be much higher than about 80 per cent for the two plates.

---

[1] Luckiesh, Trans. Illum. Eng. Soc., **9**, p. 472; 1914.

[2] Gage, Trans. Illum. Eng. Soc., **11** (2), p. 1050; 1916.

[3] Coblentz, this Bulletin, **14**, p. 507: 1918. It is relevant to add that the photo-electric cell was under test for accuracy in comparison with a bismuth-silver thermopile. The latter requires more skill in handling, but it is nonselective and its responses are proportional to the incident energy. The quartz lens spectrometer was constructed for ultra-violet radiometric work several years ago; this Bulletin, **7**, p. 245, 1911; **10**, p. 38 (Fig. 5), 1912. The mirror spectrometer and fluorite prism is described in this Bulletin, **10**, p. 1, 1913; and the thermopile is described in this Bulletin, **11**, p. 132, 1914.

[4] In this Bulletin, **9**, p. 116, 1912, data are given on the transmission of green fluorites, some of which had marked absorption bands.

2. GELATIN LIGHT FILTERS

In photographing the infra-red spectrum using plates sensitized with dicyanin (which makes it possible to photograph beyond 1μ) it is necessary to absorb the scattered visible rays by means of deep red glass or some other filter which is highly transparent to the infra-red.

In Fig. 1, curves *B* and *C* give the transmission of two gelatin filters (No. 724A and No. 740A; thickness 0.8 mm, made by the research laboratory of the Eastman Kodak Co.) which appear well adapted as a screen for absorbing the visible rays when photographing infra-red lines.

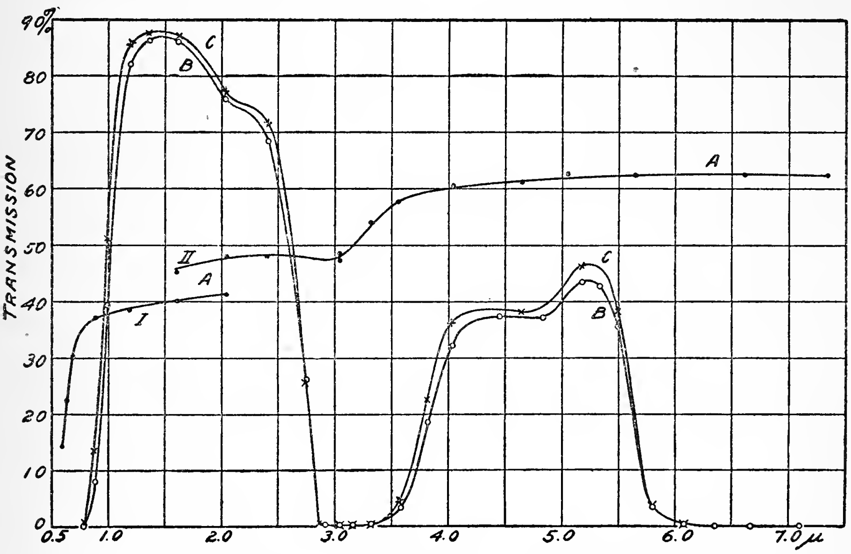

FIG. 1.—*Transmission of purple fluorite, A, and of light filters, B and C*

A comparison of these curves with those of transparent gelatin [5] and of nitrocellulose [6] shows that the absorption of the dye does not extend far into the infra-red.

The Wratten and Wainright filters, F 29 and H 45, are also well adapted for infra-red filters.[7]

3. GOLD-PLATED GLASS

It is well known that metals are opaque to infra-red rays, and that some of them have narrow bands of high transmission in the visible or ultra-violet spectrum. Gold has a band of low reflectivity and great transparency in the region of 0.5μ.

[5] This Bulletin, 7, p. 648; 1911.

[6] Publication No. 97, p. 42, Carnegie Institution of Washington, 1908.

[7] Paschen, Ann. der Phys., 43, p. 858; 1914.

The samples examined (Fig. 2) were thin films of gold deposited upon Crookes's neutral-tint glass (Fig. 17) by means of cathode disintegration.[8] The small absorption band at 0.58μ is caused by the glass (see Fig. 17). Curve *B* gives the transmission of a thinner film of gold mounted upon crown glass. The data are of

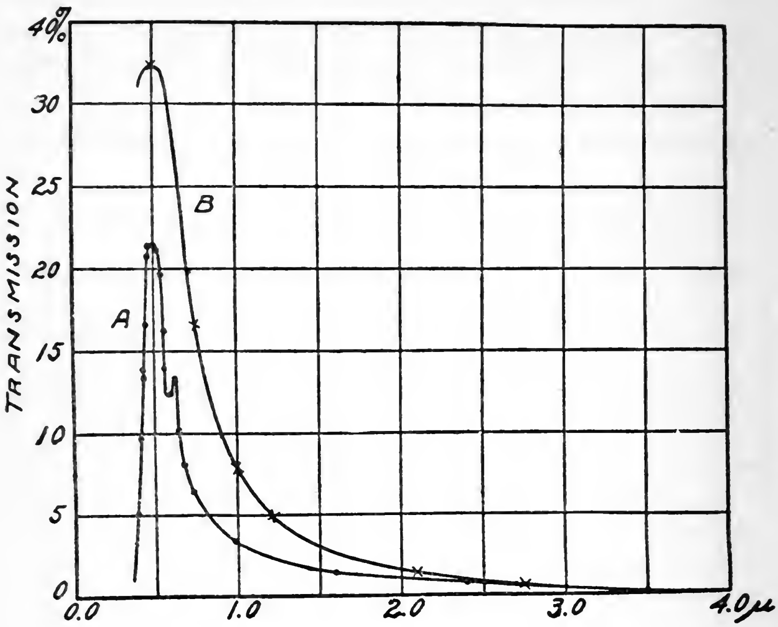

FIG. 2.—*Transmission of a thin film of gold on glass*

interest in connection with the question of absorbing the infra-red rays in eye-protective glasses.[9]

4. MOLYBDENITE

The transmission spectrum of a thin lamina ($t = 0.007$ mm) of molybdenite, MoS_2 is given in curve *A*, Fig. 3. This sample [10] was examined in connection with the photoelectric properties of this mineral. The wavy character of the transmission curve, beyond 2.5μ, is attributable to interference,[11] which did not occur in the thick samples previously examined.[12]

These data are of interest in connection with the photoelectric sensitivity of molybdenite, to be published in a subsequent paper.

[8] Taken from goggles made by the American Optical Co., Southbridge, Mass.

[9] See this Bureau's Technologic Paper No. 93; 1917.

[10] National Museum sample No. 53046, from Wakefield, Ottawa Co., Canada.

[11] See further illustrations by Crandall, Phys. Rev., 2 (2), p. 343; 1913.

[12] Publication No. 97, p. 41, Carnegie Institution of Washington, 1908.

5. CHROMIUM SULPHATE

The sample of chromium sulphate examined, $Cr_2(SO_4)_3+18H_2O$, was a large flat crystal, 0.24 mm in thickness, which appeared green in transmitted light. The presence of the large amount of water of crystallization[13] renders this substance very opaque to infra-red rays, as illustrated in curve *B*, Fig. 3. The transmission of a 1 cm layer of 1 gr. of $CrSO_4$ in 100 cc of water is given in curve *A*, Fig. 4.

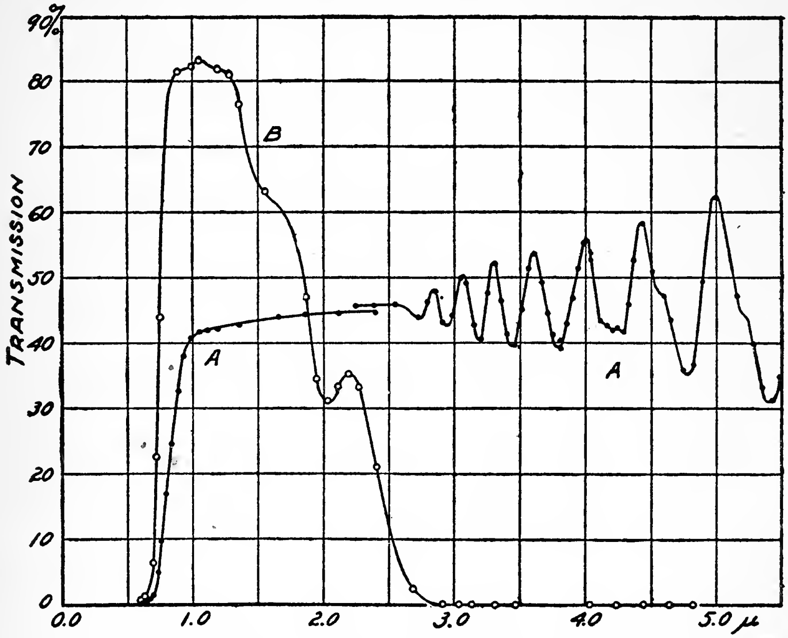

FIG. 3.—*Transmission of, A, Molybdenite and, B, chromium sulphate*

6. CHROME ALUM

The transmission of solution of 10 gr. of potassium chromium sulphate $CrK(SO_4)_2$ in 100 cc of water is given in curve *B*, Fig 4. The cell containing glass windows was 1 cm in thickness.

7. COBALT CHLORIDE

The transmission of a 1 cm layer of 10 gr. of cobalt chloride, $CoCl_2+6H_2O$ in 100 cc of water is given in curve *C*, Fig. 4. The transmission spectra of these salts are of interest in connection with the question of making screens for transmitting narrow regions of the spectrum. Unfortunately, none are more efficient than some of the glasses discussed on a subsequent page.

---

[13] This Bulletin, 7, p. 619; 1911.

8. SOLUTIONS OF NICKEL SALTS

In a previous search for a substance which absorbs all the infra-red rays, nickel chloride was examined.[14] In the present work the transmissions of a 1 cm layer of nickel sulphate, $NiSO_4 + 7H_2O$, nickel nitrate, $Ni(NO_3)_2$, and nickel acetate, $Ni\ (C_2H_3O_2)_2$, were determined, the concentration in all cases being 10 gr. of salt in 100 cc of water. The transmission curves are given in Fig. 5. They are of interest in showing a sharp absorption band at 0.7μ, followed by complete opacity at 1.4μ caused by the absorption of water.

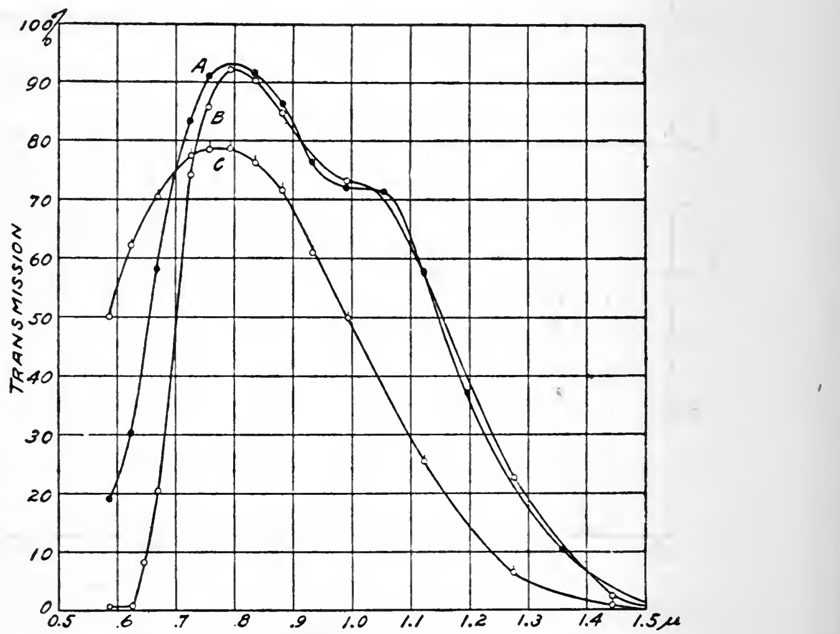

FIG. 4.—*Transmission of solutions:* $A = CrSO_4$, $B = CrK(SO_4)_2$, $C = CoCl_2$

None of these salts are as suitable as cupric chloride for absorbing the infra-red rays.

III. GROUP 2.—VARIOUS GLASSES

It would be futile to attempt to determine the transmissive properties of all of the numerous glasses which are obtainable under different trade names but which have a characteristic color—red, yellow, blue-green, etc.

The color of the same kind of glass may be different for different melts and for different parts of the same melt; and it depends upon

[14] This Bulletin, 7, p. 658; 1911.

the length of time of the heat treatment.[15] However, while this has a marked effect in the visible spectrum, as will be noticed presently, the effect of the coloring matter usually does not extend far into the infra-red.

In view of the fact that, for most of the glasses herein described, the transmission in the visible and ultra-violet had already been determined,[16] the present data relate principally to the infra-red. The application of some of these glasses in eye-protective goggles has already been described.[17]

1. RED GLASSES

Red glasses include (1) copper ruby, which is most commonly found as flashed ruby, consisting of a thin layer of intensely

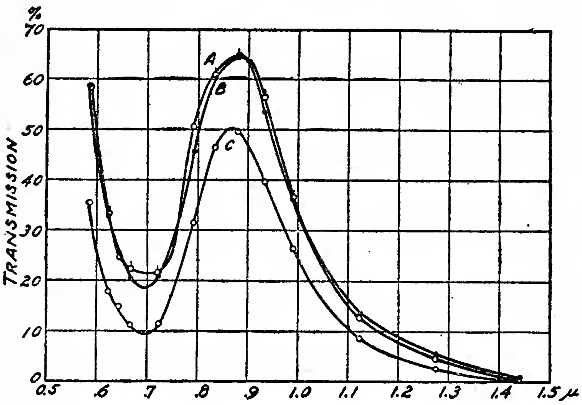

Fig. 5.—*Transmission of nickel salts in solution: A, sulphate, B, nitrate, C, acetate*

colored glass covering a layer of colorless glass, (2) gold ruby, and (3) selenium red, in which selenium is the essential coloring agent.

In Fig. 6, curves *C* and *D* ($t=2.48$ and 1.95 mm), give the transmission of two copper ruby glasses, the latter being a flashed ruby glass.

Curve *A*, Fig. 6, gives the transmission of a Corning[18] high-transmission selenium glass, G 24; thickness, $t=5.90$ mm. It is conspicuous for its absorption band at 1.1μ, which is found in ordinary glass containing iron as an impurity. (See curve *A*, Fig. 20.) This property makes it useful as an absorption glass in

[15] Gage, Trans. Illum. Eng. Soc., 11 (2), p. 1050; 1916.
[16] Luckiesh, Trans. Illum. Eng. Soc., 9, p. 472, 1914; Gage, Trans. Illum. Eng. Soc., 11 (2), p. 1050, 1916.
[17] This Bureau's Technologic Paper No. 93, 1917.
[18] Kindly supplied by the Corning Glass Works, Corning, N. Y.

the eyepiece of an optical pyrometer. Combined with the light blue-green glass, Corning G 124JA (Fig. 11, *C*), to limit more effectively the deep red end of the spectrum, a narrower monochromatic red line is produced. This combination has been found useful and well adapted for optical pyrometer measurements.

Curve *B*, Fig. 6, gives the transmission of a sample of Schott's red glass, No. 2745 ($t=3.18$ mm), which is conspicuous for its extraordinary transparency of 85 to 90 per cent, extending from

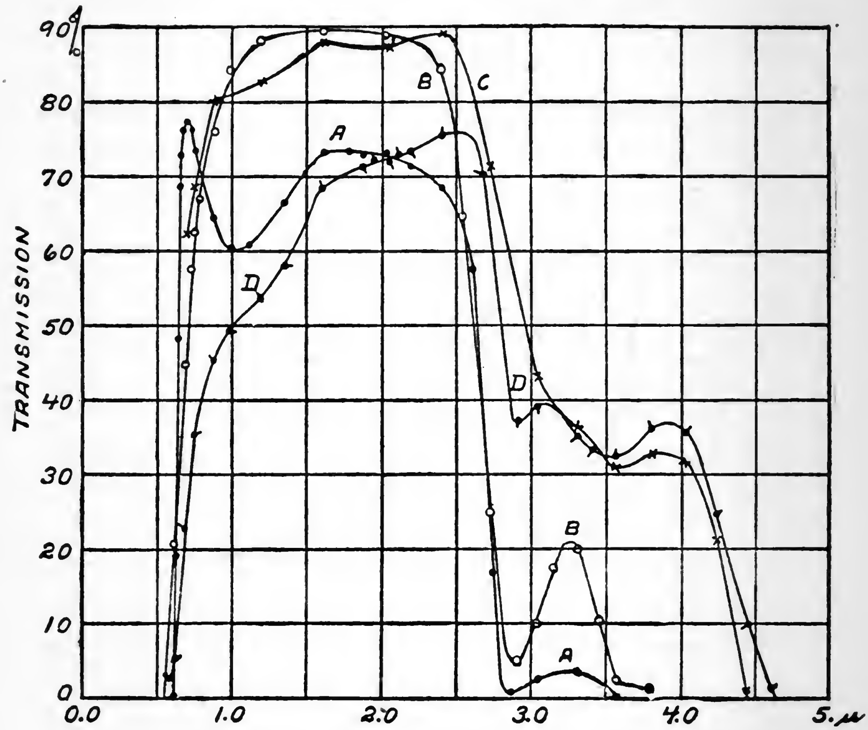

FIG. 6.—*Transmission of red glasses*

1 to 2.4μ. Using a 1 cm cell of water and a red glass, a strong transmission band is obtained at about 1μ.

2. ORANGE GLASSES

The samples examined were Corning G 34 and G 36 ($t=3.55$ mm and 5.65 mm, respectively), curves *B* and *A*, Fig. 7. They have the characteristic absorption band of the selenium red glass, Fig. 6, but probably contain a substance which increases the transparency at 3 to 4μ. In the visible, the transmission terminates rather abruptly at about 0.55μ. Chemically, these glasses belong to the group of selenium red and noviol yellow glasses.

3. YELLOW GLASSES

In Fig. 8, curves *A* and *B*, give the transmission of two fluorescent yellow glasses, Corning G 371 ($t=4.90$ mm) and G 311 Y ($t=4.97$ mm). The coloring matter is presumably uranium, which produces the absorption bands at 0.92μ and 1.55μ.

Corning noviol (shade B, $t=2.88$ mm), curve *C*, Fig. 8, (also Fig. 19) is a light-colored, yellow glass used for protecting the eyes from ultra-violet light. This glass is opaque [19] to ultra-violet

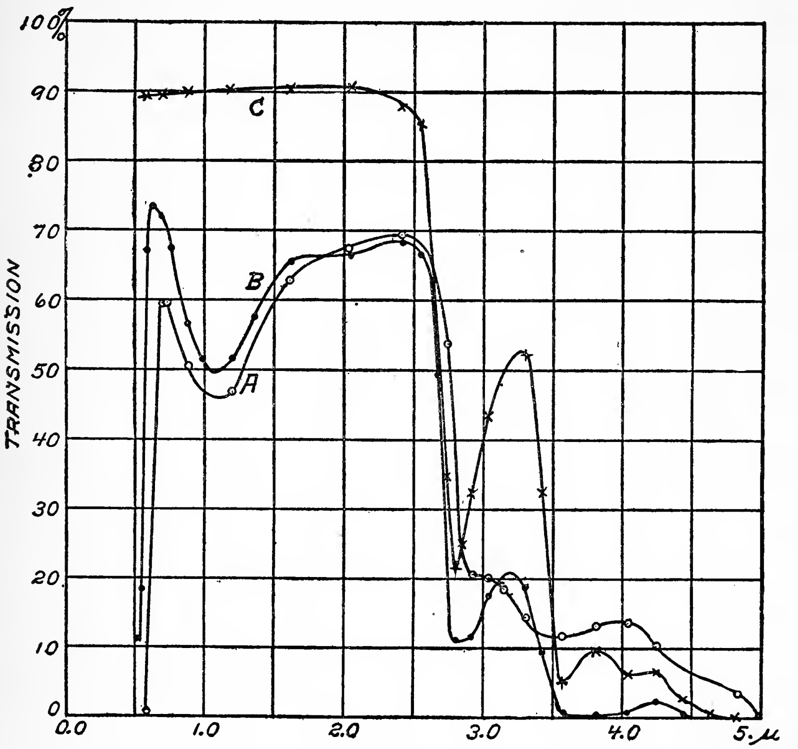

FIG. 7.—*Transmission of Corning orange-colored glasses: A, G 36; B, G 34; C, Corning Pyrex glass (t=1.55 mm)*

radiations (as indicated by the dotted line in Fig. 8, which represents data taken from Gage's paper). An examination of various shades of this glass shows that the coloring matter does not have a marked effect upon the infra-red transmissions.[20]

"Noviweld" is a dark-yellow, eye-protective glass which absorbs the blue and violet, and transmits red, yellow, and green. The samples examined were kindly provided for examination by Dr.

[19] Gage, Trans. Illum. Eng. Soc., 11 (2), p. 1050; 1916.

[20] This Bureau's Technologic Paper No. 93; 1917. In this paper, Fig. 1, curve *B*, is novial "Shade *A*" and curve *C*, is noviol "shade *C*."

H. P. Gage, of the Corning Glass Works. The maker's number is Corning G 391DM. The transmissions of various shades of this glass are given in Fig. 9, the thickness in all cases being very close to 2.2 mm. Curves A = shade 30 per cent; B = shade 3; C = shade $4\frac{1}{2}$; D = shades 6 and 7. These glasses are unique for their great opacity to infra-red rays.

4. GREEN GLASSES

The infra-red transmission of a yellowish-green glass, Schott's copper oxide, No. 431 III (t = 3.43 mm), is given in curve A, Fig. 10. Curve B gives the transmission of a sample of slightly

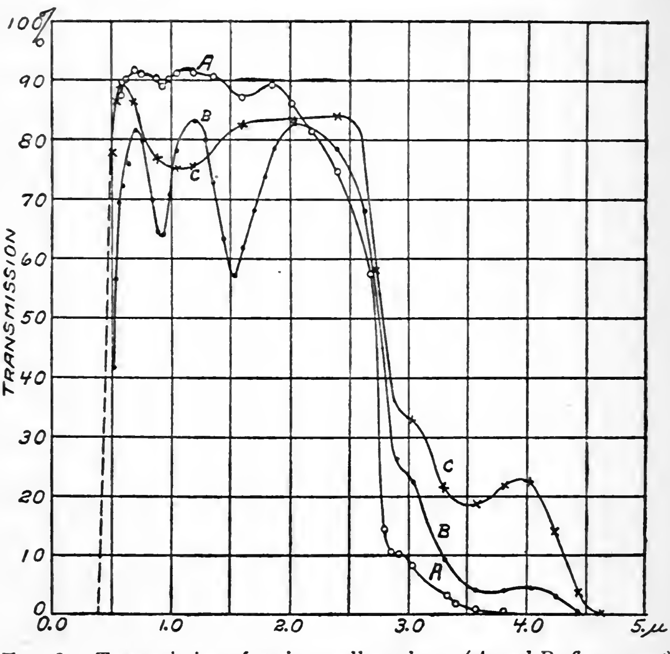

FIG. 8.—*Transmission of various yellow glasses* (*A and B, fluorescent*)

bluish-green glass; Corning high-transmission green G 171 ON (t = 5.11 mm). The infra-red transmission of Corning signal green G 40 (curve C, Fig. 10, t = 4.93 mm.) differs but litttle from the preceding sample. The dotted part of the curve, illustrating the transmission in the green and blue, was taken from the paper published by Gage.[21]

The transmission of Crookes's sage-green glass, ferrous No. 30, also of a blue-green glass, is given in Fig. 17, while in Fig. 18, curve A, is given the transmission of a light yellowish-green glass which is conspicuous for its high transmission in the infra-red.

[21] Gage, Trans. Illum. Eng. Soc., **11** (2), p. 1050; 1916.

Combined with a water-cell and noviol glass, these glasses give narrow transmission bands in the visible spectrum.

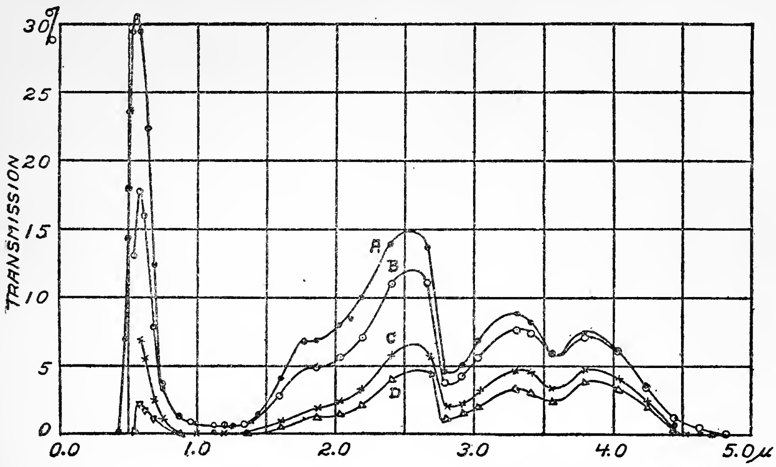

Fig. 9.—*Transmission of Corning "Noviweld" glasses*

5. BLUE-GREEN GLASSES

The transmission curves of several glasses, made by the Corning Glass Works and having marked opacity for infra-red rays, are given in Fig. 11. The light greenish-blue glass, Corning G 124J

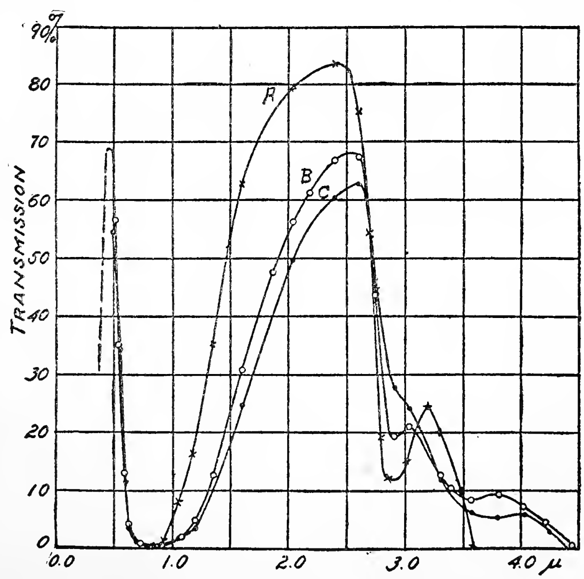

Fig. 10.—*Transmission of green glasses*

($t=2.6$ mm), curve B, is obtainable under the trade name, "Heat absorbing glass." The transmission of a sample of another melt, marked G 124J″ ($t=2.90$ mm), is given in curve A.

Curve *C* gives the transmision of a very light blue-green glass, G 124JA ($t = 1.5$ mm), which has a high transmission (50 per cent) in the visible spectrum. (See also Fig. 17.) Curve *D* gives the transmission of a very dark yellowish-brown glass, G 124IP ($t = 2.0$ mm), which is one of the most opaque glasses yet examined.

6. BLUE GLASSES

A number of blue glasses were available for examination. In Fig. 12, curve *A* gives the transmission of a cobalt blue glass ($t = 2.43$ mm). Curve *B*, Fig. 12, gives the transmission of a high transmission blue, Corning G 401Z ($t = 6.56$ mm). Curve *C*, Fig. 12, gives the transmission of Schott's blue F 3086 ($t = 2.58$ mm).

Curve *D*, Fig. 12, gives the transmission of an interesting blue glass (probably of foreign make $t = 2.09$ mm) obtained from the

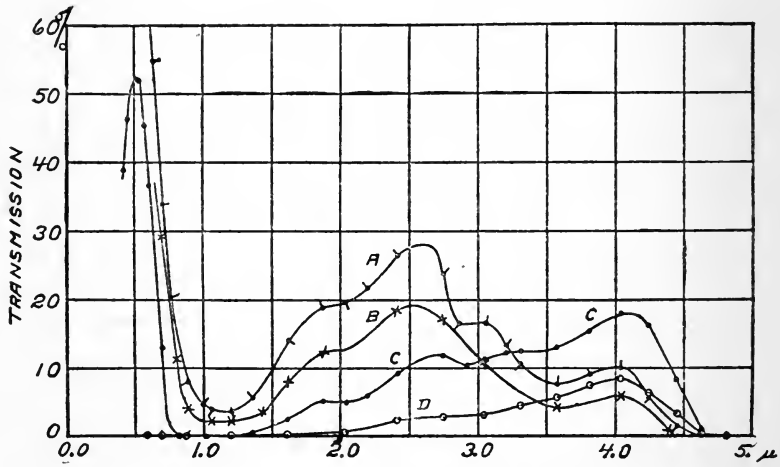

Fig. 11.—*Transmission of blue-green glasses*

Bausch & Lomb Optical Co. The transmission curve of a similar glass, Corning blue-purple ultra G 585 ($t = 3.13$ mm) is given in curve A, Fig. 13. These two glasses are remarkable for their extraordinarily high, narrow, transmission band at 0.82μ. Combined with a 1 cm cell of water and an amber glass to eliminate the blue, a very intense band of radiations is transmitted at 0.7 to 0.8μ, which can be used in scientific investigations. Using a solution of copper sulphate or cupric chloride, to eliminate the transmission band at 0.7μ, leaves a band of high transmission in the violet.

Curve *B*, Fig. 13, gives the transmission of a pale blue-green glass, Corning, G 584 ($t = 3.70$ mm). Curve *C* gives the transmission of a light blue-green glass, Corning, G 171 IZ ($t = 3.23$ mm).

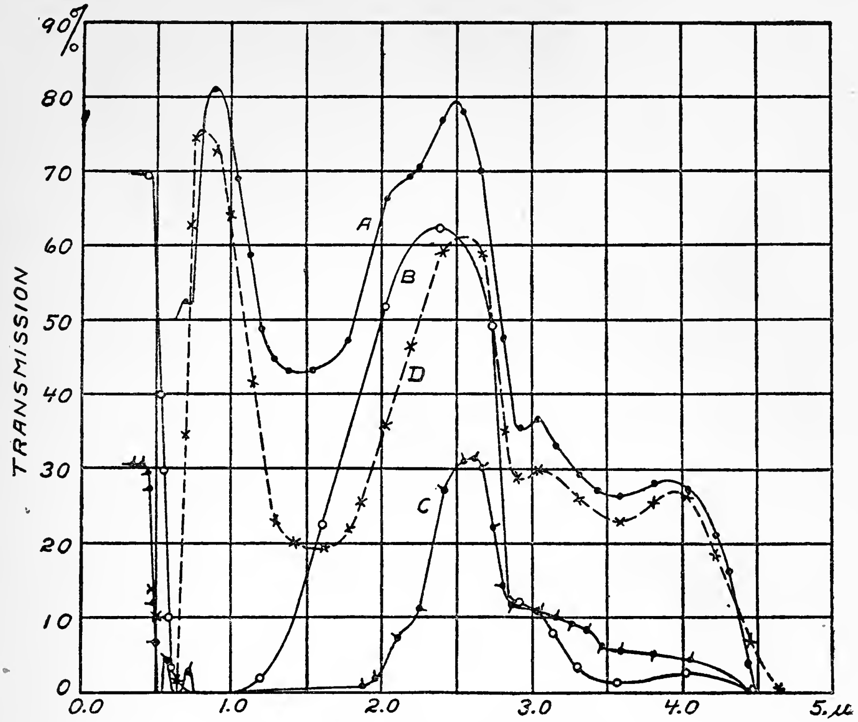

FIG. 12.—*Transmission of blue glasses.*

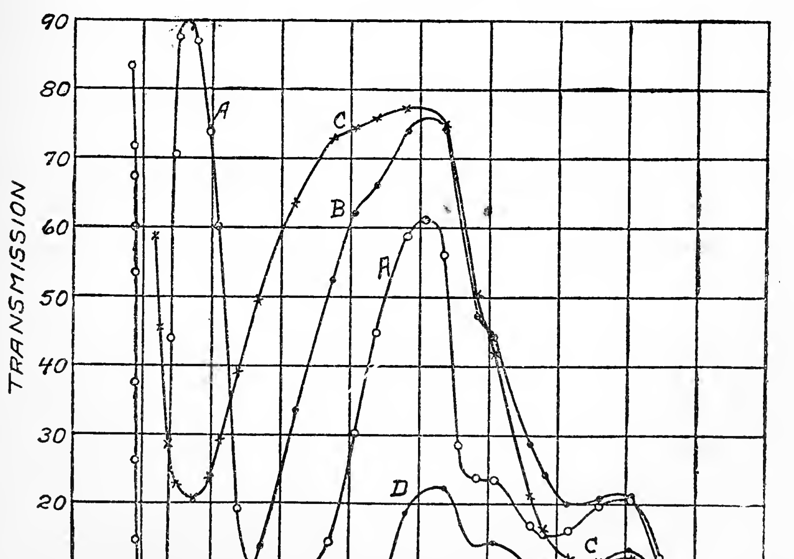

FIG. 13.—*Transmission of various Corning glasses: A, **blue purple ultra**, G 585; B, pale blue-green, G 584; C, light blue-green glass, **G 171 IZ**; D, dark blue, G 53*

Curve *D*, Fig. 13, gives the transmission of a dark blue glass, Corning, G 53 ($t = 2.40$ mm).

All these glasses are conspicuous for their great opacity in the region from 1 to 2 μ.

7. PURPLE GLASSES

Curve *A*, Fig. 14, gives the transmission of a deep purple glass ("electric smoke," purple: $t = 1.90$ mm) made by the American Optical Co. Curve *B* gives the transmission of a thicker ($t = 2.46$ mm), darker sample of the same material which transmits only the deep red of the visible spectrum. This glass has an unusually

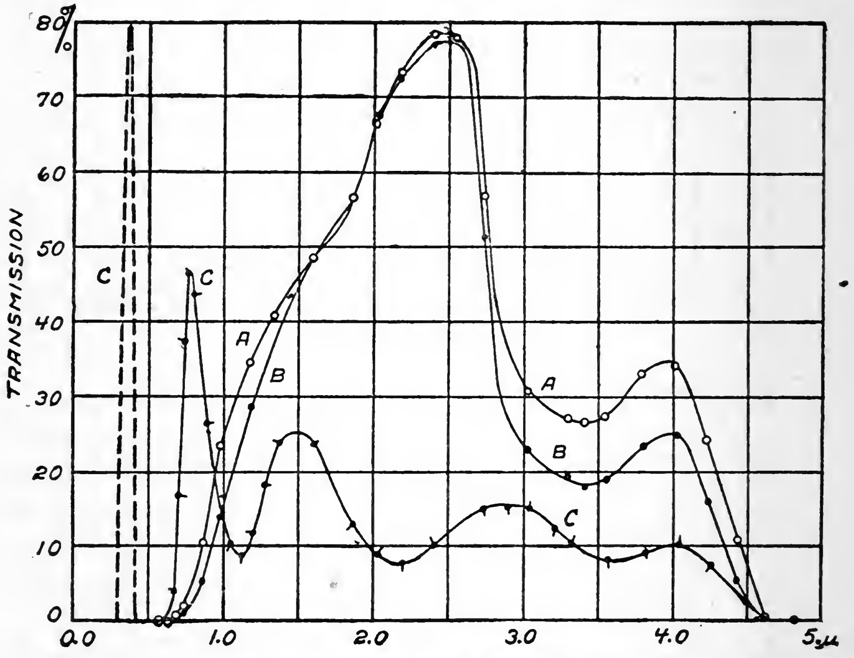

FIG. 14.—*Transmission of purple glasses*

high transmission at 2.5μ which makes it valuable as a screen for transmitting these radiations. Curve *C*, Fig. 14, gives the transmission of an interesting purple glass, Corning, G 55 A 62 (the new number is G 586 A; $t = 2.85$ mm), which has a narrow band of high transmission in the violet,[22] 0.36μ, and another band of high transmission at 0.77μ. A third transmission band occurs at 1.5μ. It would be interesting to know what substance causes these absorption bands, which occur at the roughly harmonic wave lengths (0.27μ?), 0.55μ, 1.1μ, and 2.2μ. The band at 3.6μ is commonly found in glasses and hence is not to be consid-

[22] Data supplied by Dr. K. S. Gibson.

ered as belonging to the coloring matter. Using a cupric chloride solution and a purple glass, the 0.38μ band is transmitted. Using a cell of water and a noviol glass, the band at 0.77μ is transmitted.

Another Corning glass, G 586 J transmits only the ultra-violet band, 0.36μ, the band at 0.77μ being suppressed to an immeasurable value.

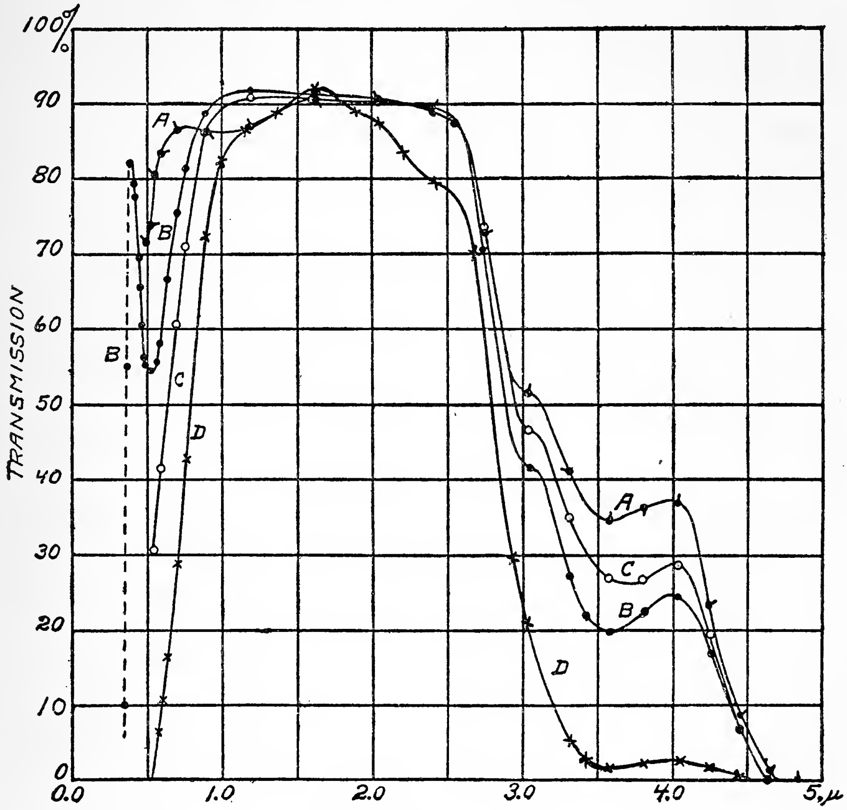

FIG. 15.—*Transmission through amethyst glasses.* (*A, is a colorless glass, A. O. C. Lab. No. 58*)

8. AMETHYST GLASSES

The amethyst color in glasses is the result of absorption in the yellow-green. As shown in Fig. 15, the absorption in the infrared is the same as that of white crown glass. (See Fig. 17.) Curve *B*, Fig. 15, gives the transmission of a dark sample of amethyst (shade C, from A. O. C.;[23] $t = 2.11$ mm). The data in the ultra-violet are from Luckiesh.[24]

[23] American Optical Co., Southbridge, Mass.

[24] Luckiesh, Trans. Illum. Eng. Soc., 9, p. 475; 1914.

Curve *C* gives the transmission of a deep wine-colored sample of unknown origin ($t=1.92$ mm). Curve *D*, Fig. 15, gives the transmission of a Corning red-purple glass, G 172 B. W. 5 ($t=4.43$ mm), which is conspicuous for its high transmission between 1 and 2.5 μ (see the ruby glasses) and its abrupt terminations at 0.5 and 3.5 μ.

9. BLACK GLASSES

Black, or "smoke," glasses are commonly used for eye protection. The different kinds vary greatly in their infra-red transmission. In Fig. 16, curve *A* gives the transmission of a very dark spectacle glass (of unknown origin, $t=1.86$ mm) which has been in use in the laboratory. Curve *B* gives the transmission of Schott's black glass, No. 444 III ($t=3.6$ mm), which is unusually opaque to infra-red radiations.

Curve *D*, Fig. 16, gives the transmission of a sample of smoke glass, shade D ($t=2.45$ mm), obtained from the Bausch & Lomb Optical Co. The sample, curve *C* ($t=2.91$ mm), evidently has the same composition, although its source is unknown. It is probably a Jena glass. These two samples are conspicuous for their high, narrow, transmission band at 0.75μ.

10. CROOKES'S GLASSES [25]

As a result of an extensive investigation, Crookes [26] has produced glasses designed, respectively, for (1) absorption of infra-red ("heat") rays, (2) absorption of ultra-violet rays, (3) high transmission of luminous rays, and (4) low transmission of luminous rays for the reduction of the glare of the sun on expanses of snow or reflected from water.

Neutral-tinted glass has a smoky, neutral tint which enables one to perceive objects in their natural colors, as is true of the smoke, or black, glasses just described. The shades *A* and *B* ("light" and "dark") of Crookes's neutral-tint glass have a high transmission in the visible. In the infra-red the lighter shade, curve *A*, Fig. 17 ($t=1.96$ mm), absorbs but little more than ordinary white crown glass (curve E, $t=2.18$ mm). Curve *B*, Fig. 17, gives the transmission of a sample of dark neutral tint ($t=2.00$ mm).

The complex absorption band at 0.50 and 0.58μ is found in didymium. This part of the curve was obtained with a glass prism, using either a thermopile or photoelectric cell as a radiometer.

---

[25] Kindly furnished by the American Optical Co.

[26] Crookes, Phil. Trans. Roy. Soc., 213, p. 25; 1914.

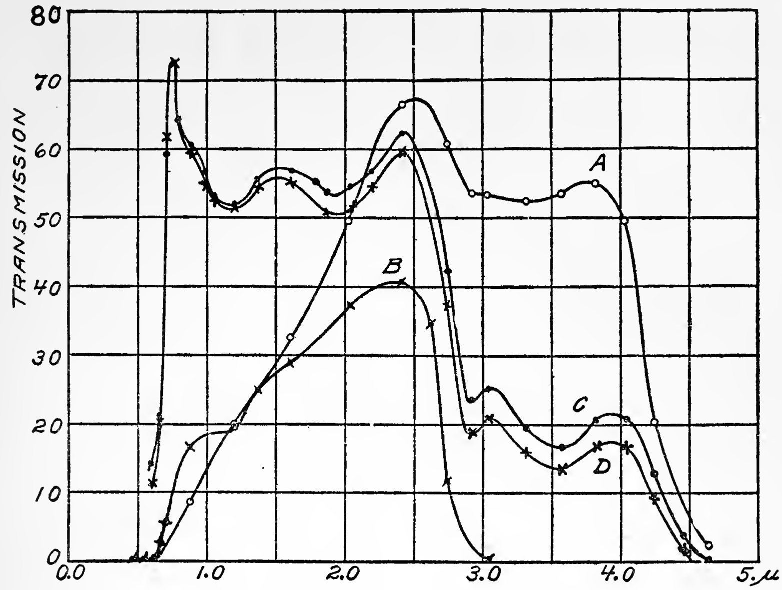

FIG. 16.—*Transmission of black glasses*

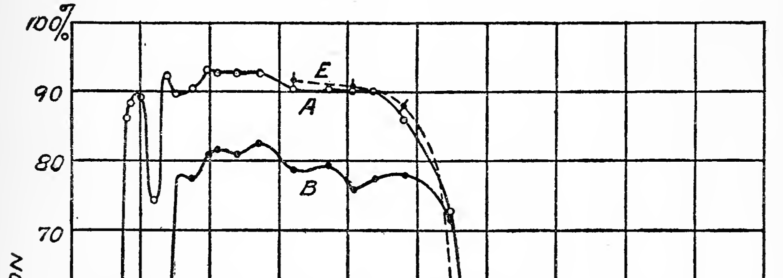

FIG. 17.—*Crookes's glasses: A, light (t=1.96 mm.); B, dark (t=2.00 mm); C, ferrous No. 30, sage-green (t=1.98 mm); D, blue-green glass (A. O. C. Lab. No. 59; t=1.93 mm). (A and B are Crookes's neutral-tint glass.) E, white crown glass (t=2.18 mm)*

According to Gage,[27] this glass absorbs the 0.359μ band of carbon, but transmits the 0.388μ band of the carbon arc.

Crookes's sage-green (A. O. C., Ferrous No. 30) is another interesting glass, having a high absorption in the infra-red, curve *C*, Fig. 17 (t=1.98 mm), and a band of high transmission (45 per cent) at 0.53μ in the green. Combined with a water cell (or better still, cupric chloride solution), this glass enables one to obtain visible radiations free from infra-red rays.

A blue-green glass (A. O. C., lab. No. 59, t=1.93 mm), which transmits about 40 per cent in the visible, is illustrated in curve *D*, Fig. 17. In the infra-red it is more opaque than the sage-

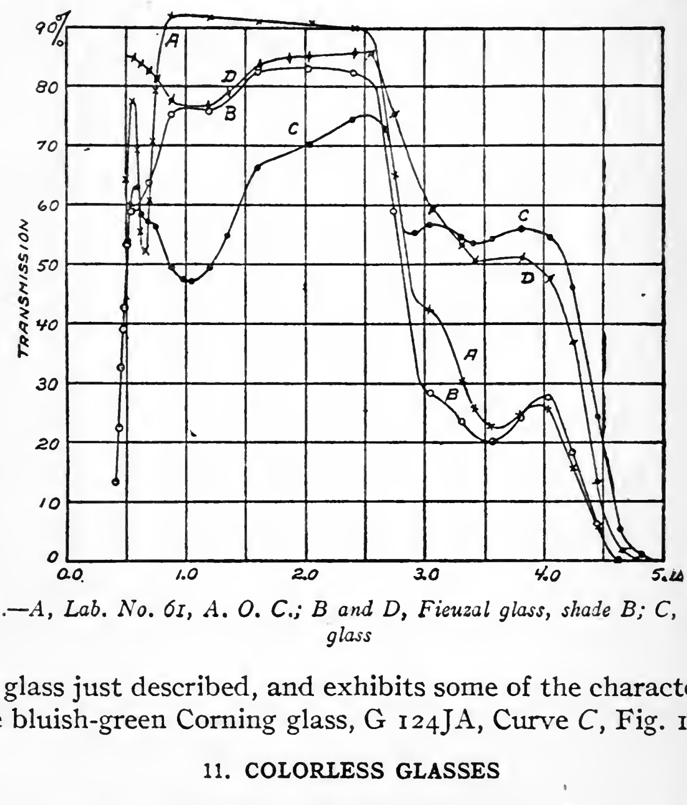

FIG. 18.—*A, Lab. No. 61, A. O. C.; B and D, Fieuzal glass, shade B; C, Hallauer glass*

green glass just described, and exhibits some of the characteristics of the bluish-green Corning glass, G 124JA, Curve *C*, Fig. 11.

11. COLORLESS GLASSES

The transmission curve of a white crown glass is given in Fig. 17, curve *E* (t=2.18 mm). It is of interest in comparison with yellow and amber-colored glasses which have a high absorption in the violet, but which show little or no absorption in the infra-red, caused by the coloring matter.

Pyrex glass, from the Corning Glass Works (colorless, thickness 1.55 mm), has a marked absorption band at 2.8μ, as is true of

[27] Gage, Trans. Illum. Eng. Soc., 11 (2), p. 1050; 1916.

all glasses containing a high percentage of silica. (See curve C, Fig. 7.)

Window glass contains iron, which causes a greenish color. This is produced by an absorption band that has its maximum at 1.1μ. (See curves A and C, Fig. 20; $t=2.11$ and 3.3 mm.) Curve C gives the transmirsion of a sample (battery jar) which had a faint bluish tinge.

Lab. No. 58, of the American Optical Co., is a colorless glass which has a marked absorption in the ultra-violet. As shown in curve A, Fig. 15, the absorption (thickness of sample 2.04 mm)

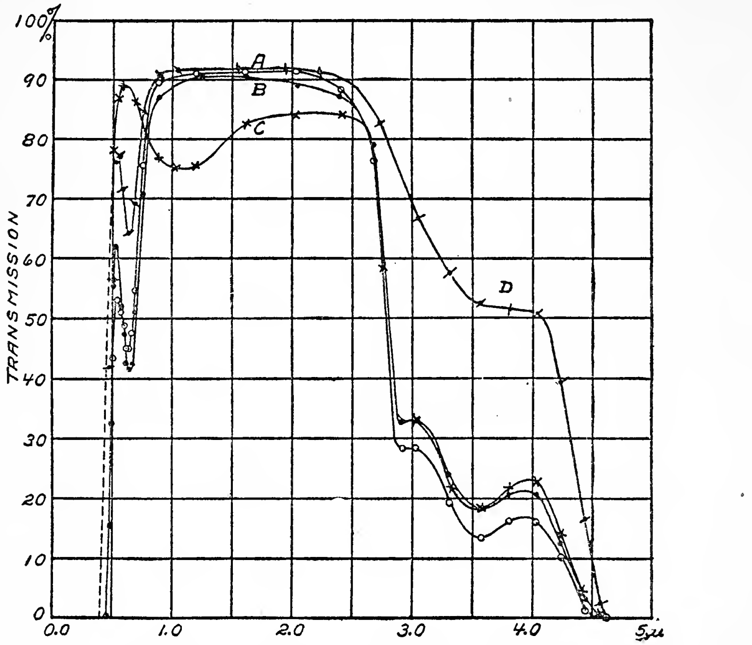

FIG. 19.—*Euphos, shade B, B, from Bausch & Lomb ($t=3.1$ mm); A (B. S. scrap material, $t=3.30$ mm). Corning Noviol, shade B, C. Akopos green, curve D*

in the infra-red is the same as that of white crown glass. Viewed edgewise, this glass shows a light brownish color.

12. UNCLASSIFIED GLASSES

Lab. No. 61, of the American Optical Co., is a light yellowish-green glass having a narrow absorption band at 0.65μ. (See curve A, Fig. 18; thickness 2.09 mm).

Fieuzal glass (shade B, curve B, Fig. 18; thickness 2.04 mm), from the American Optical Co., is a dark greenish-yellow glass of French origin. It has the characteristic absorption band at 1.1μ, of glasses, containing iron, and the didymium band at

0.6μ. Curve *D*, Fig. 18, gives the transmission of a sample (t = 1.98 mm) purporting to be a Fieuzal glass, obtained from an optician. Its transmission curve has properties in common with the Fieuzal and the Hallauer glass.

Hallauer glass (thickness of sample 1.41 mm) is an eye protective glass of German origin. It has practically the same tint as the Fieuzal glass. However, as shown in curve *C*, Fig. 18, its transmission is quite different in the infra-red.

Euphos glass is an eye protective glass of German origin. It has a slightly more greenish tint than the Fieuzal glass. As

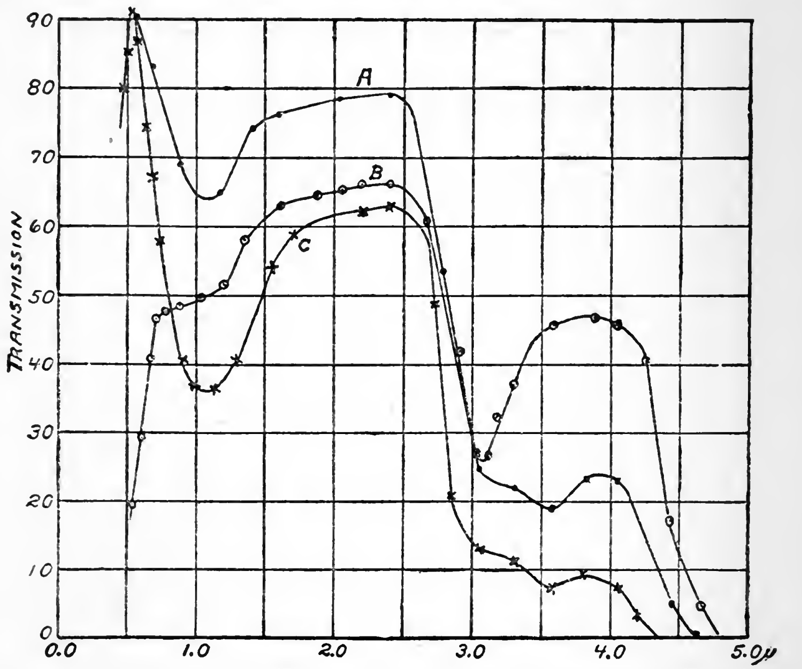

FIG. 20.—*Transmission of plate window glass, A and C and of amber bottle glass, B*

shown in curve *A*, Fig. 19 (thickness 3.30 mm), the absorption band at 1.1μ is absent and the band at 0.62μ is more sharply defined than in the Fieuzal glass.

Curve *B*, Fig. 19, gives the transmission of a sample of Euphos glass (thickness 3.1 mm), which was obtained from the Bausch & Lomb Optical Co. The transmission is practically the same as that of the preceding sample, the source of which is unknown.

Amber-colored bottle glass.—The sample examined, curve *B*, Fig. 20 (t = 2.2 mm), was a fragment from an ordinary brown beer bottle. Its absorption in the ultra-violet is quite as effective as some of the new, highly advertised protective glasses.

Akopos green ($t = 1.58$ mm), curve *D*, Fig. 19, is another eye-protective glass. It is to be noticed that all of these glasses protect the eye from ultra-violet rays, but they have little or no protective value for infra-red rays, other than that which obtains in colorless glass.

IV. SUMMARY

This paper gives the spectral transmission of various substances, especially colored fluorite, light filters, and colored glasses.

Some of the substances provide a simple means for obtaining narrow spectral bands of radiant energy of high intensity and large area, without the employment of a spectroscope. By properly combining them one can obtain a screen having a narrow band of high transmission at 0.38μ, 0.5μ, 0.55μ, 0.7μ, 0.8μ, 1μ, and 2.2μ.

The data on glasses are also useful in giving information as to their applicability for protecting the eyes from injurious radiations. (See Table 1.)

WASHINGTON, January 31, 1918.

APPENDIX

TRANSMISSION DATA OF VARIOUS GLASSES [28]

The quartz mercury vapor lamp is one of the most common sources of injury to the eye, from ultra-violet rays. Injurious effects result even after these rays are reflected from fabrics, etc. The ultra-violet rays are very insidious in that the inexperienced and unsuspecting experimenter does not feel the effects until several hours after exposure to these rays. The milder cases of injury consist of granulation of the eyelids and pain through the optic nerve. This may continue for several days. Plotnikoff (Photochemische Versuchstechnik) says that repeated exposure to the ultra-violet rays from these lamps causes permanent injury to the eyesight. Reports have come to the writers' notice of the deleterious effects of ozone and nitrous oxide upon the bronchial tubes, etc., which gases are formed by the ultra-violet rays from quarts mercury vapor lamps.[29]

Mercury vapor lamps having glass tubes are not known to be injurious.

It is extremely important to protect the eyes from ultra-violet rays by means of colored glasses, the most efficient ones being amber, yellow, and greenish-yellow glasses. The most efficient glass, used singly, for absorbing the infra-red and the ultra-violet is the Corning new "Noviweld," as shown in Table 1, which gives the per cent of total radiant energy transmitted by various glasses, some of whose spectral transmission curves are given in the foregoing pages.

The radiations from the quartz mercury vapor lamp are mostly in the visible and in the ultra-violet, only a few weak emission lines being in the infra-red. A new Cooper-Hewitt, also an R. U. V. quartz mercury lamp, were used in making these determinations. These lamps become red-hot. Hence, in order to eliminate the radiations of hot quartz from these transmission data, the bismuth silver thermopile, which was used to measure the radiation intensities, was covered with a 1 cm cell, having thin quartz windows and containing distilled water, both of which substances are very transparent to ultra-violet rays, but which are very opaque to infra-red rays. As shown at the bottom of Table 1, white crown glass and mica absorb much of the extreme ultra-violet, but they are not sufficiently opaque to protect the eye from these injurious rays.

The transmission of the radiation from a magnetic arc lamp, through some of these protective glasses, is given in the seventh column of Table 1. A 1 cm cell of water (just described) eliminated the radiation from the electrodes. In making these measurements the electrodes were mounted in a hand-operated mechanism to control the steadiness of the arc. These data are of interest to workmen doing arc welding.

The transmission of these glasses (Table 1, column 5) was determined also for the radiations from a (500-watt stereopticon) gas-filled tungsten lamp which emits considerable visible and infra-red radiation. In this test no water cell intervened between the thermopile and the sample under examination. The data are instructive in comparison with the spectral transmission curves already described.

[28] See Technologic Paper No. 93, revised edition, which gives Table 1 of the present paper without the data on the transmission of solar radiation.

[29] For a thorough discussion of the injurious effects of radiant power upon the eye, the following papers should be consulted: Verhoeff and Bell, Proc. Amer. Acad. Arts and Sci., **51**, p. 630, 1916. Birge, Trans. Ilum. Eng. Soc., **10**, p. 932, 1915. Amer. Jour. Physiol, **36**, p. 21, 1914; **39**, p. 335, 1916.

The last column of Table 1 gives the transmission of solar radiation through various glasses. In making these measurements a single thermojunction was exposed, through a rock salt window, to the solar radiation, on a very clear day (Mar. 16, 1918, Q=1.1 gr. cal. per cm.^{2} of horizontal surface).

Instructive data on the ultra-violet component in various artificial lights have been published by Bell,[30] who concluded that no commercial illuminant radiates, for any ordinary working value of illumination, enough ultra-violet energy to be at all harmful, provided one exercises ordinary discretion in keeping unpleasantly bright light out of the eyes.

TABLE 1.—Transmission of the Radiations from a Gas-Filled Tungsten Lamp, the Sun, a Magnetite Arc, and from a Quartz Mercury Vapor Lamp (no Globe) Through Various Substances, Especially Colored Glasses

Color	Trade name	Source a	Thickness in mm	Transmission, per cent			
				Gas-filled tungsten	Quartz mercury vapor	Magnetite arc	Solar radiation
Greenish-yellow	Fieuzal, B	A. O. C.	2.04	71.6	26.9	46.0	63
Do	Fieuzal, 63	F. H. E.	1.80	75.5	34.3	55.0	72
Do	Fieuzal, 64	F. H. E.	1.65	50.7	22.0		
Do	Euphos	B. S.	3.27	78.9	25.0		
Do	Euphos, B	B. & L.	3.12	78.8	24.7	53.0	64
Do	Akopos green	J. K.	1.58	84.6	29.5	59.0	74
Do	Hallauer, 65	B. S.	2.36	70.3	17.7		
Do	Hallauer, 64	F. H. E.	1.35	58.7	25.9		55
Smoky green	G 124, IP	C. G. W.	2.81	.4	.2		
Yellow-green	Noviweld, 30%	C. G. W.	2.14	5.1	7.8		9
Do	Noviweld, shade 3	C. G. W.	2.20	3.4	4.2	2.7	
Do	Noviweld, shade 4½	C. G. W.	2.20	1.6	1.2	.8	
Do	Noviweld, shade 6	C. G. W.	2.17	.9	.4	.2	.9
Do	Noviweld, shade 7	C. G. W.	2.17	.8	.2		
Amber	No. 213	P. W. G.	5.57				43
Do		B. S.	3.12	51.6	15.2		
Do	Bottle	B. S.	2.2				49
Do	Saniweld, dark	J. K.	1.32	78.1	10.6	43.0	50
Orange	G 34	C. G. W.	3.57	56.9	17.0		47
Yellow	Noviol, shade A	C. G. W.	2.00				81
Do	Noviol, shade B	C. G. W.	2.88	74.1	32.2	56.0	75
Do	Noviol, shade C	C. G. W.	2.00				72
Sage green	Ferrous No. 30	A. O. C.	1.95	5.3	17.5		17
Yellow-green	No. 61	A. O. C.	2.10	82.7	28.6		72
Blue-green	Lab. No. 59	A. O. C.	1.93	3.7	17.3	11.5	
Do	G 124JA	C. G. W.	1.53	5.3	21.5	12.5	19
Black	Smoke, C	B. & L.	2.26	65.3	31.2	52.0	60
Do	Smoke, D	B. & L.	2.45	50.9	16.0	39.0	43
Neutral tint	Crookes, A	A. O. C.	1.97	85.3	46.1		89
Do	Crookes, B	A. O. C.	2.00	75.7	32.0	64.0	69
Gold plate	Pfund	A. O. C.		2.6	7.2	1.2	12
Do. (darker)	Pfund	A. O. C.			1.3		

[30] Bell, Proc. Amer. Acad. Arts and Sci., 48, p. 1, 1912.

a A. O. C, Amer. Optical Co., Southbridge, Mass.; C. G. W, Corning Glass Works, Corning, N. Y.; B. & L, Bausch & Lomb, Rochester, N. Y.; J. K, Julius King Optical Co., New York City; F. H. E, F. H. Edmonds, Optician, Washington, D. C.; P. W. G, Penna. Wire Glass Co., Philadelphia, Pa.; B. S. Bureau of Standards; scrap material, source unknown.

TABLE 1—Continued

Color	Trade name	Source	Thickness in mm	Transmission, per cent			
				Gas-filled tungsten	Quartz mercury vapor	Magnetite arc	Solar radiation
Colorless	Lab. No. 58	A. O. C.	1.58	83.3	40.0	66.0	88
Do	Lab. No. 57	A. O. C.	2.00		51.9		
Amethyst	Shade C	A. O. C.	2.11	82.8	44.3		79
Purple	Electric smoke	A. O. C.	1.89	36.6	2.2		11
Do	G 55 A 62	C. G. W.	2.85	17.4	17.0		16
Blue	Shade D	B. & L.	2.09	37.6	20.7	39.0	
Blue, dark	G 53	C. G. W.	2.51	2.9	3.9		
Blue-green	G 171-IZ	C. G. W.	3.21	46.6	41.7		
Blue, pale	G 584	C. G. W.	3.75	24.9	25.2		
Red-purple	G 172 BW 5	C. G. W.	4.93	72.4	26.5		
Blue-purple	G 585	C. G. W.	3.13	35.8	34.0		41
Red	Selenium	C. G. W.	2.90	67.8	7.9	48.0	48
Do		Schotts'	3.22	69.4			46
Do	Flashed	B. S.			4.8		
Colorless	Window	B. S.	1.85		59.5		82
Do	Crown	B. S.	1.56		64.9		92
Do	Aqueduct	P. W. G.	4.75				81
Brown	Mica	B. S.	1.30		35.4		
Colorless	do	B. S.	.09		43.1		
Clear	Water	B. S.	10.00	34.2	[a] 56.0		
Do	do	B. S.			[b] 83.0		[b] 76

[a] Transmission of 1 cm cell having glass windows.

[b] Using a 1 cm. cell having thin quartz windows. The transmission of this cell, for the total radiation from the quartz mercury vapor lamps, no water cell intervening, was 36 per cent.

The results of the foregoing investigation show that, in glasses which have a high absorption in the violet and ultra-violet (thus producing yellow and amber colored glasses), the effect of the coloring matter does not, as a rule, extend into the infra-red. Such glasses usually absorb but little more than colorless glass in the infra-red.

Glasses which have a wide absorption band in the red and yellow (blue-green glasses) usually have a marked absorption in the infra-red.

In view of the diversity of glasses on the market and the uncertainty of their protective properties, the foregoing brief summary will give the reader a rough estimate of the protective properties that may be expected when purchasing untested glasses whose origin is unknown.